BIOMIMETIC APPROACHES IN STRUCTURAL DESIGN: A REVIEW OF POTENTIAL APPLICATIONS AND CHALLENGES IN THE CONTEXT OF BANGLADESH

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ABSTRACT

Biomimicry is the emulation of nature's design principles and strategies. It revolutionizes the field of structural engineering by offering innovative solutions that are efficient, sustainable, adaptable and aesthetically pleasing. The aim is to dive into the realm of biomimicry in structural design, specifically focusing on its potential applications, challenges, sustainability and efficiency within the unique context of Bangladesh. Through careful examination, several remarkable biomimetic strategies have been unveiled, including but not limited to the application of fractal geometries for enhanced structural efficiency, inspired from natural forms for increased load-bearing capacity, and the utilization of self-healing mechanisms for improved durability. They offer prospective solutions to address difficulties particular to Bangladesh, such as minimizing the impacts of regular monsoons, guaranteeing resilience against seismic activity, and optimizing material consumption in resource-constrained regions. However, this research also emphasizes the limitations associated with turning biomimetic concepts practical considerations. The cultural, economic, and regulatory features of Bangladesh represent distinct challenges that must be negotiated to enable successful adoption. Furthermore, the shortage of locally relevant biomimetic research and knowledge needs a joint approach, encompassing academia, business, and government authorities. In conclusion, this analysis sheds light on the untapped potential of biomimicry in changing structural design methods inside Bangladesh. By implementing cutting-edge biomimetic concepts with the country's particular difficulties and potential, a route emerges toward innovative and sustainable structural solutions that harmonize with both nature and society. This study intends to promote more research, dialogue, and collaboration in the dynamic sector of biomimicry and structural engineering, with the ultimate goal of fostering resilient, ecologically sensitive constructed environments in Bangladesh.

Keywords: *Biomimicry, Sustainable, Resilient Environments, Structural Design.*

1. INTRODUCTION

Biomimicry is derived from the Greek bios which means life and mimesis which leads to imitations. Biomimicry is the study which deals with the design procedures and process inspired from the nature to solve human problems and considerations. This reverent mimicry is a completely novel strategy indeed, a revolution in a civilization that is used to taming or "improving" nature. The Biomimicry Revolution ushers in a new era that is cantered on what we can learn from nature rather than what we can extract from her, in contrast to the Industrial Revolution (Benyus, 2017). Biomimicry in architecture involves designing buildings and structures that mimic or are inspired by natural processes, forms, or functions found in the natural world. While biomimicry is gaining popularity in sustainable architecture worldwide, it might not have been widely adopted in Bangladesh at that time.

Biomimetics is an approach toward sustainable whole systems design that has the potential to develop ecological solutions to a given problem. However, it does not necessarily contribute to ecological solutions (Blizzard & Klotz, 2012; Mcmahon & Hadfield, 2007). Gebeshuber et al. argue that designing sustainable products is independent from the specific design method (Gebeshuber et al., 2009). Use of biomimicry helps in the understanding of the physical attributes of natural elements and thus it will help in designing more sustainable designs and solutions.

Figure 1: Bio inspired design (Jahan & Faiza, 2020).

Biomimicry is seen as a transfer of innovation from nature to humanity because of the superior mechanical structure inherent in natural systems. The categories of organisms and structures in nature emerge without any discernible human motivation. There is no denying that sustainable building practices are beneficial to both the environment and human health. It has been demonstrated that a 2% increase in the initial investment cost (to encourage sustainable design) can result in a 20% reduction in total building cost. According to McDonough and Braungart, “From my designer’s perspective, I ask: Why can’t I design a building like a tree? A building that makes oxygen, fixes nitrogen, sequesters carbon, distils water, builds soil, accrues solar energy as fuel, makes complex sugars and food, creates microclimates, changes colours with the seasons and self-replicates. This is using nature as a model and a mentor, not as an inconvenience. It’s a delightful prospect.”

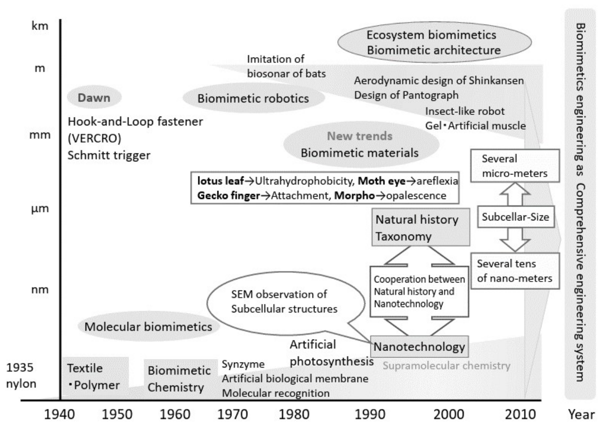

Figure 1: Historical trend of biomimetics. Source: Shimomura (2015).

The field of biomimetics encompasses a broad spectrum of applications and holds great potential for stimulating innovation (Bar-Cohen, 2006). Since the turn of the millennium, the field of biomimetics has witnessed a gradual expansion outside its traditional domain of chemistry, extending its reach into the realms of material science and engineering. This expansion has primarily occurred at the centimetre scale. Moreover, the field of biomimetics is being progressively utilized in the realm of architectural and urban design, specifically at scales ranging from meters to kilometres (Shimomura, 2015).

2. METHODOLOGY

This research follows a methodology that seeks to systematically review the existing literature on biomimetic approaches in structural design, analyse relevant case studies, and evaluate the viability of implementing biomimetic principles in the context of Bangladesh. Key components of the research methodology are as follows:

2.1 Reviewing of Existing Literature

The literature was searched using academic databases, architectural journals, books, and reliable online sources. Only biomimetic structural design studies applicable to Bangladesh were reviewed. To identify biomimetic structural design themes, trends, and concepts, relevant literature was organized and synthesized. This included global case studies and best practices analysis.

2.2 Case Study Analysis

Several international and regional case studies of biomimetic structural design were examined. Case studies were chosen to demonstrate biomimicry's diverse architectural uses. Case studies were assessed for biomimetic principles, sustainability, and Bangladeshi relevance. Local materials, climate, and culture were considered.

2.3 Assessment of Feasibility in the Context of Bangladesh

Architecture, engineering, and environmental science experts were consulted to determine biomimetic structural design's feasibility in Bangladesh. These experts discussed local biomimetic design challenges, opportunities, and adaptations. Local Considerations: Bangladeshi climate, resources, and building regulations were examined to determine how biomimetic design principles could be integrated.

2.4 Data Analysis

Literature review, case studies, and expert consultation findings were categorized and interpreted using qualitative data analysis. Common biomimetic structural design themes, challenges, and opportunities in Bangladesh were identified.

2.5 Future Challenges

This study aims to analyse the future issues associated with the application of biomimicry in architecture, with the ultimate goal of formulating a comprehensive conclusion and providing relevant recommendations.

3. LITERATURE REVIEW

The study of the composition and operation of organic frameworks as models for the composition and construction of contemporary materials and machinery is what is meant by "bio inspired design." It is widely acknowledged that it is interchangeable with terms such as biomimicry, bio mimesis, and bio gnosis, and that it is also comparable to biomimetics. Aristoteles is credited as being the first person to investigate and analyse metaphor (Fischer, 2011).

Sustainability requires a design that won't compromise future solutions. The primary goal of biomimicry architecture is sustainability. By focusing on practical arrangements seen in nature, biomimicry expands the arrangement space. Nature maintains a constant biological process in the surroundings. Biomimicry is incorporating ecological functions into the built environment. Environmental and social issues such as waste creation, energy and material use, and greenhouse gas emissions are linked to the built environment generated by humans (Nkandu & Alibaba, 2018). Several studies are also found that clarifies studies ongoing to mimic the structural design of a structure using biomimicry. Shrestha and Ravichandran (2020) investigated the potential for a new foundation arrangement resembling a tree root. ABAQUS was used to identify three simplified foundation configurations and develop three more by adding sub-root and 3D Finite element models. The performance was analysed using design loads and showed that adding main roots led to a greater improvement (see Figure 2) (Shrestha & Ravichandran, n.d.).

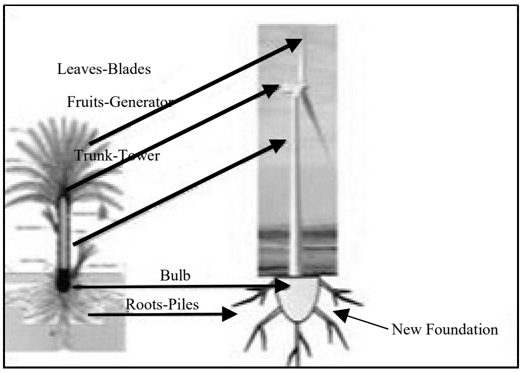

Figure 2: Potential new foundation through biomimicry.

Inspiration for structural design also came from the human skeleton. Finite element analysis is used to study human bone dynamics, modelling the humerus bone in MIMICS and analysing it in ANSYS with varied boundary conditions for tension member shapes. The stress pattern was compared to the actual bone, and an optimal model was created for the tension member from numerous models with varying member diameters. The femur bone serves as an effective compression resistance member in an adaptive column model (Sindhu Nachiar et al., 2021). The proximal bone was modelled using MIMICS and analysed using ANSYS for various compression members. The following figures illustrates the optimal model based on the appropriate form and stress pattern for changing compression member diameters.

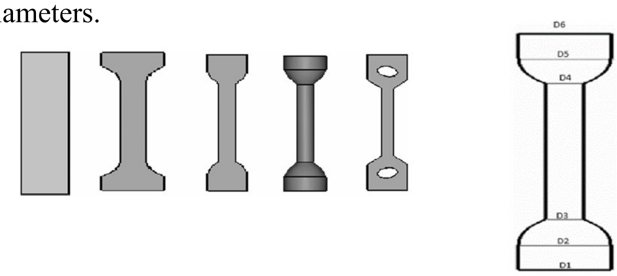

Figure 3: Optimized tension member (Sindhu Nachiar et al., 2021).

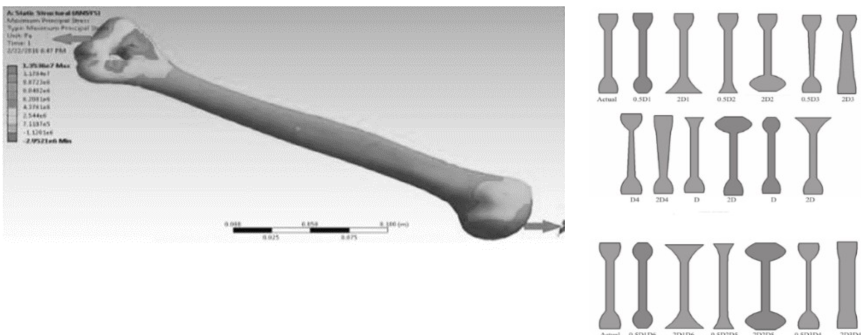

Figure 4: Stress pattern of humerus bone and varying diameter of tension member symmetrically (Sindhu Nachiar et al., 2021).

4. CASE STUDIES RELEVANT TO BANGLADESH

This 58,000-square-meter complex, surrounded by skyscrapers, is located in Taiwan's second-largest city of Taichung, the country's cultural capital. It has dramatic, fluid spaces where the wall and ceiling appear to merge seamlessly; there are no supporting beams, columns, or 90o walls. Prehistoric caves and rock shelters, man's first home, inspired its design. Catenoids curved surfaces spinning around an axis form the structure, which is technically difficult. The building has 58 concrete poured steel shelled curved wall units. The architects worked with race car engineers on structural and acoustic effects. Ito says this building has eyes, mouth, nose, and ear, just like the sense organs. In Bangladesh, such scenes are found profoundly and can also help in building up a design system that requires less mechanical support.

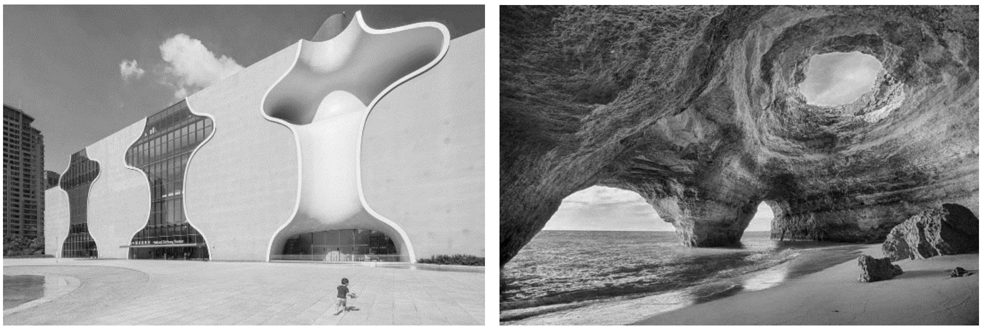

Figure: (a) National Taichung Theatre, Taiwan (b) A rock cave (S et al., 2020)

Zimbabwean termites make massive mounds to grow fungus, their main meal. The fungus demands 87 ˚F, despite ambient temperatures of 35–104 ˚F. Throughout the day, termites open and seal mound vents. Air is drawn in at the mound's base by a system of carefully regulated convection currents, pulling it into enclosures with muddy walls and up via a channel to the top of the termite wall. In order to change the temperature, working termites dig new vents and plug existing ones. The building mass warms or cools by the drawn-in outside air depending on which is hotter, concrete or air. It escapes through chimneys above the building's levels and offices. A glass-covered space between buildings lets local winds flow. From this open space, second-floor ventilation gather air. It ascends vertical supply ducts in both buildings' centre spines. Old air is replaced through floor-ceiling exhaust holes. From vertical duct exhaust, it exits the building via chimneys. Similar buildings consume almost 10% more energy than Eastgate Centre. Eastgate saved $3.5 million by replacing its air-conditioning system. These eco-friendly discounts help renters pay 20% less than nearby buildings (Fehrenbacher, 2012).

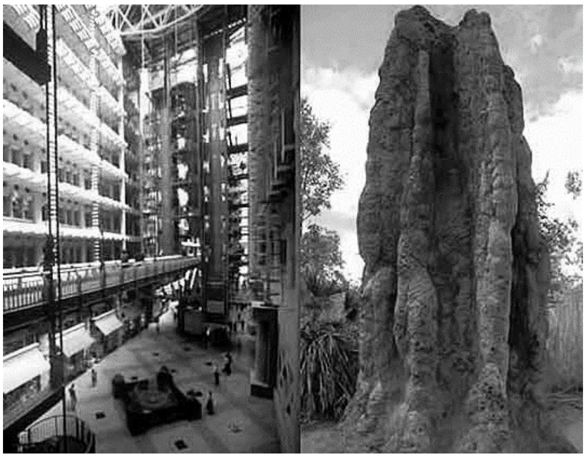

Figure: The Eastgate development centre, Zimbabwe and a Termite mound

Eiffel Tower, constructed in 1889, was designed by Gustave Eiffel, who drew inspiration from the femur, the longest and largest bone found in the human body. The femur possesses a relatively low weight-to-strength ratio, enabling it to endure substantial amounts of pressure, a characteristic that was also required for the construction of the Eiffel Tower. The human femur contains a well-structured lattice of bone fibres, contributing to its enhanced structural integrity and stability. The presence of a woven pattern within the core of the Eiffel Tower, as evident in photographs, serves as a testament to its enduring stability, irrespective of the external circumstances it encounters (Institute, 2022).

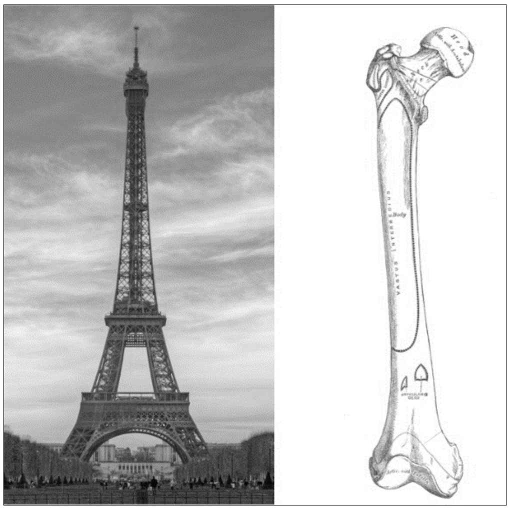

Figure: The Eiffel Tower by Gustave Eiffel a typical human femur bone.

One of London's most famous and innovative buildings is the Gherkin Tower, 30 St Mary Axe. This iconic glass-clad skyscraper, designed by Norman Foster and completed in 2003, is a classic example of biomimicry in modern architecture whose design was adopted from the Venus Basket Sponge. The Gherkin's name comes from its cucumber or gherkin like form. This distinctive design is functional. The tower's aerodynamic, curved design reduces wind resistance and turbulence, saving energy. This mimics the streamlined form of natural structures like trees and plants that have evolved to withstand wind and weather stresses. An enclosing glass exterior surrounds the building. This design mimics how leaves and plant structures let in enough sunlight while reducing heat and glare. Heating and cooling the building with the double skin saves energy. The Gherkin Tower contains a natural ventilation system modelled after termite mounds to reduce the building's dependency on mechanical heating and cooling systems. Termite mounds use convection currents to maintain a steady temperature. Cooler air is drawn in from below by warm air rising and leaving via vents at the top of the tower. Passive ventilation saves energy and improves comfort. Rainwater is harvested by the Gherkin Tower, like many ecosystems. Our curving roof collects rainwater, which we filter and utilize for irrigation and toilets. This sustainable method mimics natural recycling and resource conservation. Similar to how plants and ecosystems incorporate nature into their structures, the building incorporates green spaces and landscaping into its design. Green elements increase air quality, biodiversity, and tenant well-being while improving aesthetics (Davidson, n.d., 2009) .

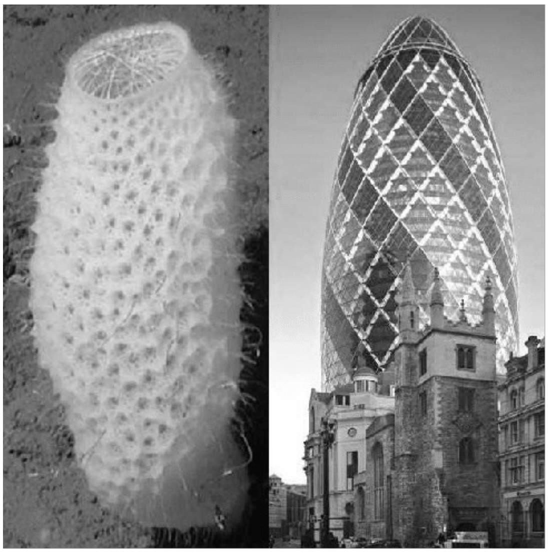

Figure: Venus Basket Sponge (left) and Gherkin Tower, London (right) (Nkandu & Alibaba, 2018).

Inspired by natural ecosystems, the Eden Project pioneered sustainable design. Geodesic domes built of hexagonal and pentagonal translucent panels form Eden Project biomes. The way soap bubbles form and efficiently enclose a huge volume with little material inspired this design (To et al., 2001). Geodesic domes enhance internal space while minimizing structural material, creating an economical and attractive construction. The Eden Project's biomes reflect rainforests and Mediterranean ecosystems. The project grows a range of plant species from around the world by analysing and recreating these natural settings. This method educates and promotes the importance of biodiversity and conservation. The design of the biomes incorporates automated ventilation systems that mirror the natural way that plants and ecosystems manage temperature and humidity. Passive ventilation maintains plant development without energy-intensive HVAC systems, saving energy. Beyond its architecture, the Eden Project promotes environmental education and research. It promotes the importance of preserving biodiversity and the interdependence of ecosystems while demonstrating biomimetic design ideas.

Figure: Eden Project, Bodelva, United Kingdom.

The recently built Central Post Office of Bangladesh, also known as "*Dak Bhaban*" is a real-life example proving mimicry is possible from any modes and it always doesn't have to be a biological one. A post box mimicry is a metaphorical interpretation of the building's design rather than a literal copy. In a number of respects, it resembles a post box. The basic building's design which is cylindrical call to remind the profile of a standard post box. The *Dak Bhaban* takes the concept of a post box and expands it to a large architectural scale. The *Dak Bhaban* is the nerve centre of Bangladesh's postal system, much like a post box is to the delivery of mail. It represents the vital role that the postal service plays in the nation. The building's design is symbolic of open lines of communication and mutual understanding, much like a post box's function in facilitating the delivery of mail. The *Dak Bhaban* is more than just a building; it is also a symbol of Bangladesh's history and culture. This building has become an iconic symbol of the nation due to its innovative design. The building's design mimicry of a post box emphasizes the importance of the postal service in bridging geographical gaps. In a pre-digital world, it is a celebration of the value of communication. From this consideration, it is also worth considering the potential future extent of mimicry originating from non-biological sources. The *Dak Bhaban* represents a ground breaking architectural concept that challenges traditional design styles and principles.

Figure: (a) Bangladesh Central Post Office, (b) A typical vintage post box of Bangladesh.

The construction of the Cox's Bazar Railway station is yet another remarkable accomplishment for Bangladesh in the field of biomimicry. The recently built railway station, which was designed by Mohammad Foyez Ullah, is now without a doubt the most aesthetically pleasing railway station in the entire nation. It has a magnificent canopy that is curved to ascend from one side and descend to the other, and it signifies the exoskeletal structure of an oval-shaped marine creature, which is most likely a shell. Additionally, provisions have been maintained within the station premises in order to accommodate a wide variety of services and amenities. The Cox's Bazar Railway Station has thus earned the title of "the nation's first iconic railway station" due to its distinctive architectural features that resonate with the varied natural landscape it is situated in. (Pieal, 2023).

Figure: Iconic railway station at Cox’s Bazar designed by Mohammad Foyez Ullah.

5. CHALLENGES AND CONSTRAINTS

The concept of biomimicry remains relatively unfamiliar and underrepresented in educational curriculum within the context of Bangladesh. Insufficient knowledge and limited educational resources pertaining to the concept can be a substantial obstacle to its implementation across diverse industries. Bangladesh encounters significant obstacles pertaining to the research and development infrastructure, which are imperative for the proficient exploration and implementation of biomimicry principles. In a developing country such as Bangladesh, the allocation of financial resources for the purposes of researching, developing, and implementing biomimetic solutions may pose a significant constraint. The integration of biomimicry into many businesses may encounter regulatory and policy challenges that necessitate attention and resolution in order to promote and facilitate its implementation. The limited availability of specialists and professionals possessing comprehensive knowledge and practical expertise in the field of biomimicry may be a constraint on the extensive implementation of this approach in Bangladesh. The task of persuading firms and individuals to adopt biomimetic approaches, which may deviate from conventional practices, might present difficulties stemming from cultural and societal influences. The nation of Bangladesh faces distinctive environmental challenges, characterized by recurrent flooding events and the presence of fragile ecosystems. Consequently, the implementation of biomimetic solutions in this context necessitates meticulous deliberation to prevent any inadvertent adverse consequences. The practice of biomimicry frequently necessitates a comprehensive understanding of the indigenous biodiversity in a given area. The limitation of accessing comprehensive biodiversity data and research can pose a challenge. The application of biomimetic solutions to bigger scales, such as infrastructure projects or industrial operations, may pose significant logistical and technical obstacles. The field of biomimicry frequently necessitates extensive periods of research and development, and ensuring the continuity of these endeavours might prove to be arduous in the absence of sustained backing. Nature inspired bio-mimetic structures cost more due to specialized materials, complex manufacturing processes, and skilled design and engineering labour. Long-term benefits like sustainability and energy efficiency may offset these upfront costs. Traditional methods use readily available materials and standardized processes, resulting in lower initial costs but higher lifecycle costs. The choice depends on project needs, priorities, and budget. The local demand for imported materials is also concerning, which stands as a huge obstacle for local brands but as the traditional methods are readily available, it would be quite costly to adhere a bio-mimetic structure.

6. FUTURE CALLENGES

The growing popularity of biomimicry demands a heightened allocation of resources towards research and development endeavours, aimed at cultivating inventive resolutions that effectively tackle the unique challenges prevalent in Bangladesh. Developing a proficient labour force equipped with specialized knowledge in the field of biomimicry will play a pivotal role in facilitating sustainable growth. The establishment of educational programs and training opportunities will be crucial. The integration of biomimicry into pertinent legislation and regulations is vital to ensure its appropriate and ethical implementation. This may necessitate arguing for modifications in the current regulatory framework. The nation of Bangladesh faces distinct environmental challenges, characterized by the escalating sea levels and recurrent instances of floods. Consequently, addressing these issues necessitates the implementation of biomimetic solutions that are attuned to these specific concerns and refrain from exacerbating them. The term "frameworks" refers to conceptual structures or models that provide a systematic approach for the availability of extensive local biodiversity data and research will play a crucial role in the effective implementation of biomimicry projects. Consequently, it may be necessary to undertake initiatives aimed at gathering and distributing this information. The process of expanding biomimetic solutions from small-scale prototypes to large-scale applications, particularly in infrastructure projects, can potentially pose many logistical, technical, and financial obstacles. The facilitation of collaboration among scientists, engineers, architects, and other professions will be imperative in order to fully exploit the potential of biomimicry. Addressing opposition to novel ideas and technology rooted in cultural and social norms may necessitate the implementation of public awareness initiatives and active involvement with local communities. Biomimicry frequently entails extensive research and development endeavours over an extended period of time. Maintaining the longevity of these efforts could present difficulties in the absence of sustained support and adequate finance. Establishing and nurturing relationships with the global biomimicry community and actively engaging with worldwide advancements are crucial for Bangladesh to sustain its leadership in biomimetic innovation.

7. CONCLUSION

Biomimicry is a very interesting advent in building design. It helps in making aesthetically pleasing buildings and also develop a sustainable building design both for structural abilities and reliability of the structure. Biomimicry in buildings can also be taken to a new level by using several cultural and traditional commodities which are not biotic into consideration. Several examples preside surrounding us which proves that biomimicry is not a luxury, rather it is a necessary. As per the traditional building design consideration of Bangladesh, it is a high time to bring in the change and also adopt the newer considerations. Biomimetic approach often requires more financial investment as the design procedure and complexity is quite time consuming, also people tend to follow the cheaper distance while constructing buildings, so it is rather a challenge to bring in an abrupt change in people's mind. The rest about biomimicry in building construction is quite easy to follow.

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